Evolving Technology

Epicardial 10-MHz ultrasound in off-pump coronary bypass surgery: A clinical feasibility study using a minitransducer

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Objective: In off-pump coronary artery bypass surgery, both plaque and calcifications and torrential back flow from side branches in the isolated coronary segment may hamper coronary anastomosis suturing. The epicardial application of an ultrasonographic minitransducer with color Doppler scanning modality was studied in off-pump coronary surgery to detect septal perforating side branches; to assess the location, size, and quality of the coronary vessel; and to visualize the anastomotic orifice before chest closure.

Methods: Thirteen patients were selected for multivessel off-pump bypass. The investigation was limited to the left anterior descending coronary artery. The anastomotic target site was chosen on preoperative and intraoperative findings. The conventionally designated site was scanned with a novel 10-MHz ultrasonographic miniprobe (15 × 6 × 9 mm) that fitted in between the cardiac stabilizer pods.

Results: In 11 of the 13 cases, the course of the left anterior descending coronary artery could be properly identified. In 3 cases detection of perforating side branches caused a change in anastomotic site. A sufficiently dry field was obtained in all 13 cases. In 11 cases the anastomotic orifice was adequately visualized.

Conclusion: During off-pump coronary surgery, 10-MHz ultrasonographic images from a minitransducer aided in the intraoperative choice of anastomotic site.

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In addition to providing intraoperative information on the location, size, and quality of the coronary artery,[1] as well as on the quality of the coronary anastomosis,[2,3] epicardial high-frequency ultrasonography may aid in isolating a segment of the coronary artery without a major side branch. In off-pump coronary artery bypass surgery (OPCAB), torrential backflow from one or more septal perforating side branches may hamper anastomosis suturing and increase the risk of technical errors. Before the arteriotomy, backflow

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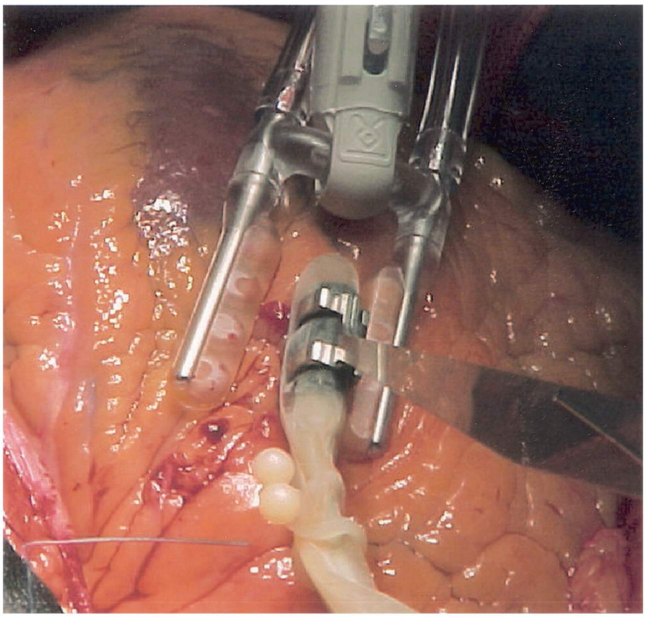

Figure 1. A 10-MHz minitransducer between suction pods of Octopus 3 stabilizer positioned along the LAD.

is hard to predict because septal perforating side branches are often not well delineated on the angiogram.

To date, during off-pump coronary surgery, the bulky size of ultrasonographic transducers[1,2] has prevented the practical application of epicardial high-frequency ultrasonography in combination with a cardiac stabilizer. Recently, a minitransducer has become available that fits in between the stabilizing pods.

The aim of the study was to assess during OPCAB the value of epicardial 10-MHz ultrasonographic imaging by using a minitransducer with color Doppler capability in locating the optimal anastomotic site without nearby side branches and without major disease and to assess whether the anastomosis could be properly captured in one image.

Methods

Patients and Preoperative Coronary Evaluation

Thirteen patients (range, 54-78 years) were selected for multivessel OPCAB. The investigation was limited to the left anterior descending artery (LAD) because of its easy accessibility and the presence of septal perforating side branches.

On the angiogram of the LAD, the stenoses were identified (luminal diameter reduction >50%) and mapped. Beyond the distal stenosis, the LAD diameter was assessed (≤1.5 mm or >1.5 mm). The presence of luminal wall irregularities suggestive of plaque were mapped as were angiographically visible side branches.

Conventional Intraoperative Coronary Evaluation

After standard anesthetic induction and preparation, the heart was exposed through a median sternotomy. On the basis of palpation and visual inspection, the course of the LAD was determined (situated superficially or buried under epicardial fat layer), the presence of plaque and calcifications was established, and the diameter of the coronary vessel (>1.5 mm) was estimated. The conventional choice of the anastomotic target site was based on preoperative and intraoperative findings, and this site was marked with a clip.

TABLE 1. Epicardial ultrasonographic evaluation of the LAD

Properly identified coronary course	11/13
Ultrasonography-guided change in arteriotomy site	3/13
Dry field or minimal flushing required	13/13
Internal thoracic artery, LAD, and anastomotic orifice in one image	11/13

Echocardiographic Equipment

A 10-MHz linear array color Doppler minitransducer (UST 5531; Aloka, Tokyo, Japan) was used that had been wrapped in a sterile sleeve. The minitransducer was 15 mm in length, 6 mm in width, and 9 mm in height. The probe has an image width of 10 mm. Imaging was performed with an Aloka SSD 5000 Prosound ultrasound system. Images were recorded on videotape and analyzed both during the scanning procedure and off line.

Scanning Procedure

After the Octopus 3 stabilizer (Medtronic, Inc, Minneapolis, Minn) was installed, the designated anastomotic target site was scanned with the minitransducer (Figure 1). Both long-axis (longitudinal) scans and short-axis (cross-sectional) scans were performed. We measured the luminal diameter and scored the presence of plaque and calcium in the coronary artery. We searched for the presence of side branches and septal perforating side branches. Scans were performed in B-mode, as well as in color Doppler mode. After occlusion of the LAD and arteriotomy, it was assessed whether the operation field was dry or whether it was necessary to flush (minimal, medium, or maximum) and whether poor visibility would hamper suturing (yes or no). After completion of the bypass, the anastomosis was scanned in B-mode and color Doppler mode with longitudinal and cross-sectional sweeps. In both scan planes, images were obtained from heel to toe. In longitudinal scans we attempted to obtain in one image heel, toe, a section of the runoff track of the LAD, and a section of the graft. The surgeon had prior scanning experience with the minitransducer (approximately 1 hour) in the animal laboratory. Interpretation of the ultrasonographic images, however, was done by a skilled and experienced ultrasonographer.

Results

The results are summarized in Table 1.

LAD Course: Ultrasonography Versus Surgical Identification

In 11 of the 13 cases, the ultrasonography-determined LAD course corresponded with its anatomic location. In one patient the LAD appeared to be obliterated, and a diagonal branch had been scanned instead. In one other patient,

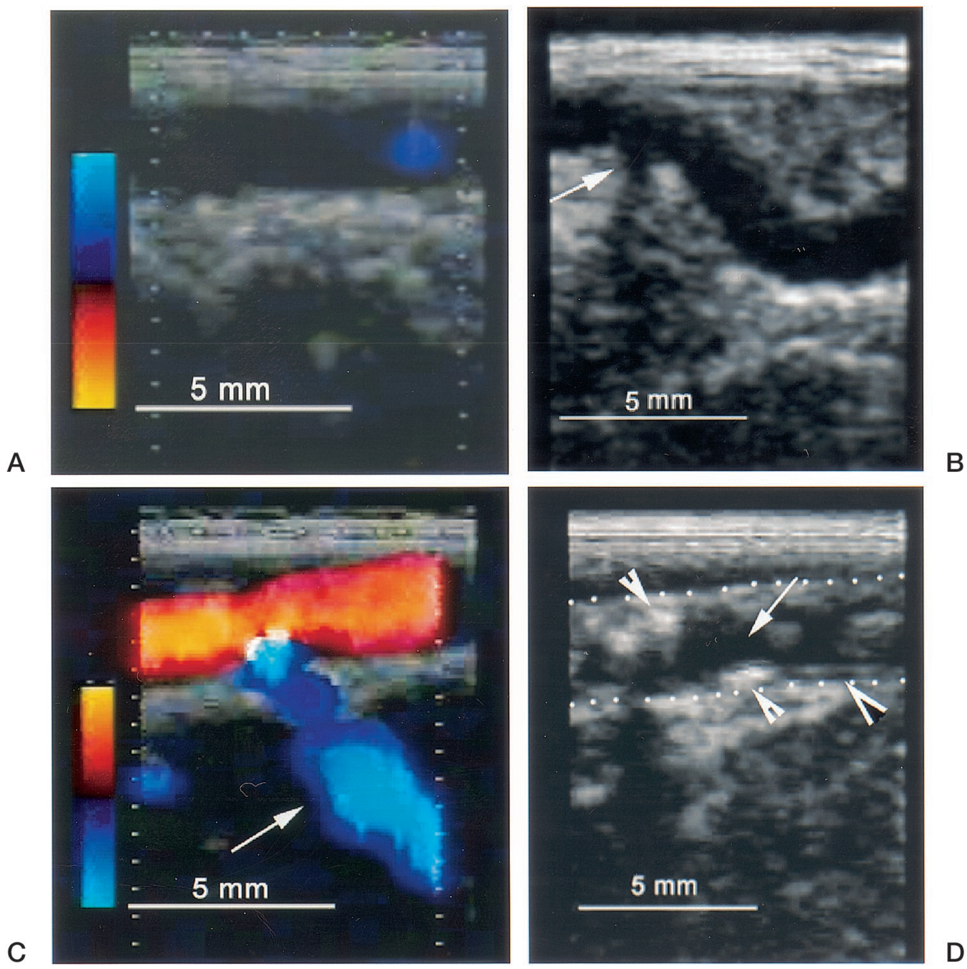

Figure 2. Images from a 10-MHz minitransducer. A, Optimal anastomotic site. No plaque and no perforating side branches were detected with color Doppler ultrasonography. B, Septal perforating side branch of LAD *(arrow)* was detected in B-mode, as well as partially intramural LAD course. C, Septal perforating side branch of LAD *(arrow)* was detected in color Doppler mode. D, Severely diseased segment of LAD *(dotted lines)* with atheromatous plaque and calcific deposits *(closed arrowheads)* and a part of the artery relatively free of plaque *(open arrowhead)* were detected. The *arrow* indicates the lumen.

initially, the accompanying vein was mistaken for the LAD because the LAD was severely atherosclerotic and obliterated. Because light pressure by the probe closed the vessel during a second scan, however, the LAD was identified properly as a calcified string.

Arteriotomy Site

The ultrasonographic evaluation of plaque and calcifications necessitated deviation from the originally designated target site in no cases. In contrast, the designated target site was altered in 3 cases when nearby septal perforating side branches were detected. Color Doppler scanning helped in locating septal perforating side branches (Figure 2). In all 13 cases the operation field was dry, or minimal flush had to be given during suturing. In one case we had to apply moderate flushing initially because the LAD appeared to have been clamped inadequately. After reclamping, the operation field was dry.

Anastomosis Image

The anastomosis image is shown in Figure 3. In 2 cases capture in one image of graft, LAD, and anastomotic orifice was unsuccessful. In 2 of the 11 anastomoses, plaque was visible because of a severely calcified artery.

Discussion

The principal results of this preliminary study during OPCAB are as follows: (1) 10-MHz epicardial ultrasonography, particularly the color Doppler mode, was effective in

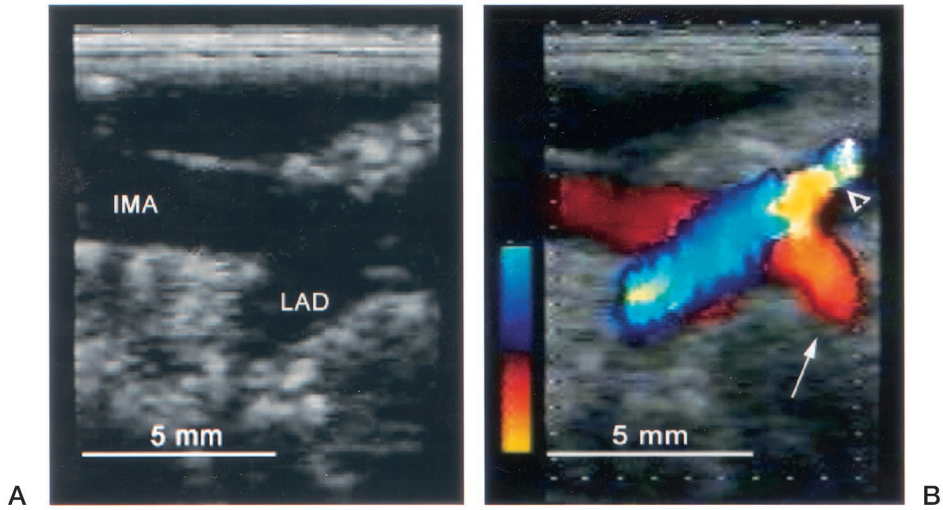

Figure 3. Images from a 10-MHz minitransducer: A, B-mode image of internal thoracic artery–LAD anastomosis, with direction of flow from left to right; B, anastomotic target site (same as in A) dictated by graft length and anastomosis opposite to septal perforating side branch *(arrow)*. During construction of the anastomosis, the site was scored as requiring minimal flushing. Diameter reduction by plaque in distal LAD was shown *(open arrow)*.

locating septal perforating side branches and led to the ultrasonography-guided change of the originally designated anastomotic site in 3 of the 13 patients; (2) during OPCAB, back bleeding from the arteriotomy was limited or absent and did not hamper anastomosis suturing in any patient; and (3) the minitransducer enabled capture of the internal thoracic artery, LAD, and anastomotic orifice in one ultrasonographic image in 11 of the 13 patients.

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In case of intense back bleeding, the endothelium may be easily injured with jets of air and carbon dioxide. In the present study in all cases a sufficiently dry operation field was obtained. It is likely that the change in anastomotic site in 3 cases has contributed to achieving minimal back bleeding that facilitated completion of the anastomosis.

In the 1980s, Hiratzka, McPherson, and associates[2,4,5] demonstrated that large epicardial high-frequency ultrasonographic probes were capable of providing information about the location, size, and quality of the coronary artery, as well as information on anastomotic morphology. In the late 1990s, Oda and colleagues[6,7] demonstrated similar results with a 7.5-MHz ultrasonographic microprobe in combination with color Doppler modality and pointed out the usefulness of ultrasonography in minimally invasive direct coronary artery bypass procedures to detect an intramyocardial course of the LAD. The present preliminary study demonstrates that coronary features can be investigated on the beating heart with a minitransducer with color Doppler modality. Its small, scalpel-like holder and flexible cable allowed optimal maneuverability of the transducer over the epicardial surface in all directions. Its image quality at least matched that of the older, more bulky transducers that restricted access. Provided adequate exposure and stabilization is obtained, similar results are to be expected when evaluating other coronary arteries.

The change in anastomotic site in 3 patients illustrates the feasibility of ultrasonography-guided intraoperative decisions during OPCAB.[3,5] Because of a lack of experience, a quality assessment of the anastomosis was considered inappropriate. It is likely, however, that this minitransducer will become a valuable tool to detect technical errors before chest closure. For this application, the resolution of the transducer should preferably be enhanced.

Preliminary, totally endoscopic OPCAB experiments in the pig revealed that the minitransducer fits through an 11-mm trocar and can be easily handled by a master-slave robotic system to compensate the surgeon for the loss of tactile feedback in the search for the optimal anastomosis site (unpublished observation).

In conclusion, the current 10-MHz minitransducer enabled ultrasonography-guided intraoperative decisions during OPCAB on the choice of optimal anastomotic site.

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